FLIGHT SYSTEM TESTBED

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Abstract

A world leader in space technology, the Jet Propulsion Laboratory (JPL) of the California Institute of Technology has over 30 years of experience in developing spacecraft systems and managing deep space missions for the National Aeronautics and Space Administration (NASA). Future scientific missions will require the rapid development of small, lightweight, high-technology, low-cost spacecraft. JPL is developing a method of meeting these requirements: a test facility specifically for supporting a rapid prototyping development environment that creates a virtual (simulated) spacecraft in which system-level evaluations of components can be carried out very early in the development cycle - long before an actual spacecraft is built.

The Flight System Testbed comprises a group of test sets that includes a permanent JPL testbed that will be used for technology "infusion" in conjunction with a series of project-specific testbeds. In technology infusion, preflight-qualified new technology - for example, an advanced lightweight camera at an early stage of development - can be integrated into a virtual spacecraft and tested for system-level functionality and interface compatibility. If the results are unsatisfactory, the device can be revised and retested; if the results are good, the item can be considered a candidate for spaceflight use. Cost and risk are both reduced - problems can be solved prior to expensive flight qualification, and advanced technology can be built into spacecraft design much earlier and with greater confidence. As new technology is accepted, it will be "infused" into project-specific testbeds. Over time, an evolving body of knowledge incorporating both new and inherited technology will be readily available to flight projects.

These improvements signal JPL's commitment to meeting the challenges of space exploration in the next century.

The Jet Propulsion Laboratory (JPL) has developed a Total Quality Management Initiative Plan "comprising vision, mission, values and strategic goals. The strategic goals are oriented toward minimizing cost, maximizing customer and employee satisfaction, and implementing small- and moderate-size missions. This paper describes specific actions the Laboratory is taking to achieve' these goals relative to future missions.

SMALL- AND MODERATE-SIZE MISSIONS

One of JPL's strategic goals states that the Laboratory will define, develop, and implement a series of scientifically exciting, publicly engaging, and financially affordable small- and moderate-size missions. To this end, JPL plans to

- Develop specific proposals for such missions, in collaboration with the National Aeronautic and Space Administration and the science community

- Evolve new management structures and processes to implement these missions at lower cost

- Develop managerial and technical design processes that minimize the complexity of systems while meeting functional requirements

- Incorporate new technology into our products that significantly enhances performance, reduces cost, and mitigates risk

- Develop space- and ground-system designs that are relatively inexpensive to operate

JPL's Flight Projects Implementation Development Office, which reports directly to the Assistant Laboratory Director for Flight Projects, is chartered to improve JPL's ability to provide low-cost, rapid-development products, and develop innovative technical and management processes that will prepare the Laboratory to meet the challenges of developing flight projects for the next century. We therefore have initiated the reengineering of the JPL's project design process, which includes the creation Of the Project Design Center and the Flight System Testbed.

REENGINEERING THE PROJECT DESIGN PROCESS

Before reengineering any process, it is essential to understand the process that is in place and its purpose. "Reengineering means abandoning long-established procedures and looking afresh at the work required to create a company's product or service and deliver value to the customer . . . . It is the fundamental rethinking and radical redesign of business processes to achieve dramatic improvements in critical, contemporary measures of performance, such as cost, quality, service, and speed." [I] One must recognize the difference between process reengineering and process improvement. If the end product remains the same, process improvement may be perfectly acceptable, although in some cases reengineering may also be appropriate. In our case, we are reengineering a process that was specifically designed to produce large, complex billion-dollar missions. Our aim now is to achieve smaller, moderate-size hundred-million-dollar missions. With a change in scope of this magnitude, it is not appropriate to simply scale down the process Instead, we must examine, reconstruct, and recraft—reengineer—the process.

A reengineering team has been formed and has identified the following characteristics of JPL's project design process that must be changed:

From	To
Sequential	Concurrent
Hierarchical	Parallel
Deferred problem resolution	Real-time problem resolution
Paper data exchange	Electronic data exchange
Stand-alone tools	Integrated tools
Limited design-space exploration	Comprehensive design-space exploration
Zero-width interfaces	Zones 'of interaction

one on one

group dynamics

THE TRANSITION FROM SEQUENTIAL TO CONCURRENT

In a typical design process, the most difficult element is attacked first and the least-difficult element is confronted last. Certainly this has traditionally been the case in the planetary exploration program at JPL. Of the three major design elements—mission, spacecraft, and mission operations system (MOS), the biggest challenge is the theoretical development of the mission design: Can we design the trajectory? Can we navigate the spacecraft? Is the launch vehicle capability sufficient to provide the required through weight? The mission design and analysis required to answer these questions and establish feasibility requires years of study. The next challenge is to design the spacecraft to fly the mission. In the past, new technology often had to be developed to execute a mission—a process that was both time consuming and expensive. It was only after the theoretical questions had been resolved and the spacecraft had been designed that operations were given serious consideration. In many of the ~~early~~ flight projects ow. develop even ~~the grossest~~ initial ~~cost~~ estimates for MOS were not developed along with the mission and spacecraft, Thus, the design process was inherently seqial: first mission, then spacecraft, and finally operations. In recent years, NASA has identified the cost of operations ~~has become~~ as a significant fraction of the overall mission cost ~~and~~ that is highly dependent on both the mission and spacecraft designs. The nature of the design process must now undergo a radical transition from sequential to concurrent, in which all three elements—mission, spacecraft, and MOS—are

throw?

1970's and 1980's

say when?

longer missions

didn't do upfront trade analysis

haven't kept miss op up to date w/ technology considered simultaneously with various technical and cost trade decisions are also considered (Figure 1).

CONCURRENT ENGINEERING

Concurrent engineering is the application of classical system engineering in an "integrated computer environment, The multidisciplinary design optimization techniques that have been developed over the last few decades are now applicable to today's project design problems. Currently system engineering is used to optimize the spacecraft's technical performance, without full regard of schedule, operations, and cost. This process can be thought of as a scalar optimization of performance, while concurrent engineering can be thought of as a vector optimization> of performance, schedules, operations, and cost. explain the difference - define

Concurrent engineering is applied both in the life-cycle process as well as in the design process, as shown in Figure __. In order to find the true system optimization, the interactions among design, fabrication, test, assembly, launch, and operations must all be considered concurrently, along with the interactions among the mission, the spacecraft, and flight operations. It is important to realize that the concurrence is not only temporal but also in conceptual design maturity, while recognizing" that the subsequent fabrication, test, and so on, will be executed sequentially in time. new fig? clarify

It should be emphasized that the PDC does not offer a "push button" design capability, rather it provides an environment in which human ingenuity combines with the power of mathematics and computers to develop the best overall project design. The PDC should clearly improve the product by providing the capability to systematically explore the design space and through the use of a computer-enhanced design process and synergistic engineering judgment enable us to arrive at the superior solution.

Concurrent engineering introduces the spacecraft design and operations design earlier into the design process so that it occurs concurrently with mission design, thus achieving an overall compression of the design process, ~~achieve~~ a more global optimized solution, and an improved estimate of the life-cycle implementation plan, including cost and schedule.

mission ~~as~~ analysis & eng = MA+E

THE TRANSITION FROM HIERARCHICAL TO PARALLEL

A hierarchical organization (Figure 2) is required for the successful implementation of large, complex billion-dollar missions, but small- and moderate-size missions require a parallel organization. In a hierarchical organization, work is divided among major groups, then subdivided among teams of specialists who collaborate to optimize their element in some degree of isolation from its contribution to the total system. Organizational control, integration, and interface management are exerted from the top down, while problem resolution is always elevated to the top. Standards vary not only from element to element but also across the organization, e.g., design margins, test philosophy, schedule reserve, cost reserve, and so on. Communication paths in the traditional hierarchical organization are concentrated among the ~~team~~ leaders rather than among the workers.

then how do workers get info?

~~element of team?~~

more access to more info

~~Freeing up from upper guys?~~

In contrast, a parallel organization (Figure 3) is "flattened out," thereby increasing the knowledge flow and redirecting the decision process—improvements that make it possible to identify and resolve problems faster and cheaper. The parallel organization contains mission, spacecraft, and operations elements so that trades and optimum solutions can be realized at early stages in the design process. The players on a multifunctional team must be willing to step out of their traditional roles or boundaries and continually maintain their focus on the mission goals even at the expense of their own element goals. The role of the team leader will therefore change from element to element, depending on the nature of the problem to be solved. If, for example, the problem under consideration is a science issue, then the lead would come from the experiment element. If, on the other hand, the problem involves avionics, operations, telecommunications, and mission analysis but is primarily a telecommunications problem, then the telecom expert would step in and take the lead. To use a sports analogy, the lead on a basketball team (a parallel organization) is usually the player who has possession of the ball, whereas on a football team (a hierarchical organization), the lead is the coach or (sometimes) the quarterback. 'The parallel organization continually emphasizes the system view over the subsystem view and continually solicits value-added actions, with the control more decentralized than the hierarchical organization. Reengineering from a

first use — define — later "multidisciplinary" need clearer explanation of connection between parallel org & multifunctionality of players

~~Does the~~ role change or ~~the~~ person change?

hierarchical to a parallel organization implies a significant paradigm shift with major cultural changes.

PROJECT DESIGN

The project design process that is used today at JPL evolved from the early spacecraft missions of the 1960s. Although the missions of the 1990s are highly complex and much larger in terms of personnel and costs than earlier missions, the design process has remained essentially the same. Over time, computer-aided engineering and design have been incorporated into the Laboratory's subsystem design processes, but not into the system design process.

The establishment of a concurrent design center is necessary to support the Laboratory's goal to develop small- and moderate-size missions for the future and to evolve management structures and processes to implement such missions, The Project Design Center (PDC) will introduce computer-aided design techniques into system- and project-level design efforts, facilitating quicker convergence of the design process, more accurate life-cycle estimating, and faster iteration for design-to-cost methodology.

Concurrent design of the mission, spacecraft, and MOS begins with the study phase, and involves designers from all technical disciplines. In the focused PDC environment, the effects of changing requirements or capabilities among the various functional areas can be quickly assessed; capability, schedule, cost, and risk can be readily understood, and appropriate system-level trade studies can be rapidly accomplished.

The overall goal of the PDC is to enhance JPL's ability to secure approval for new projects and to execute approved projects more economically. The PDC's specific goals are to

- Support JPL missions with the following characteristics:

    High science return